VOLUME VIII: CHAPTER 11

METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM BURNING OF AGRICULTURAL CROP WASTES

October 1999

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Prepared for:
Greenhouse Gas Committee
Emission Inventory Improvement Program

DISCLAIMER

ACKNOWLEDGMENTS

This document was prepared by Barbara Braatz, Randy Freed, William Driscoll, and other staff of the ICF Consulting Group, Washington, D.C., for the Greenhouse Gas Committee of the Emission Inventory Improvement Program and for Ethan McMahon and Wiley Barbour of the Office of Policy of the U.S. Environmental Protection Agency. Bill Irving, of U.S. EPA's Office of Air and Radiation, also contributed to this report. Members of the Greenhouse Gas Committee contributing to the preparation of this document were:

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1

INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating emissions of methane (CH_4) and nitrous oxide (N_2O) from burning of agricultural crop wastes. Companion chapters describe methods for estimating emissions of greenhouse gases from a variety of other sources. For example, chapters 13 and 14 address CH_4 and N_2O emissions from fossil fuel combustion.

Note that in addition to crop residue burning, burning of certain other materials also emit CH_4 and N_2O. These include prescribed burning of forests, burning of slash from the timber industry, and burning of tire piles. For states that are interested in estimating these emissions, emission factors may be available in the U.S. EPA report *Compilation of Air Pollutant Emission Factors*, also known as “AP-42” (U.S. EPA 1998a).

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in using the preferred method for estimating greenhouse gas emissions from this source. Section 4 presents the preferred estimation method; Section 5 is a placeholder section for alternative estimation techniques that may be added in the future. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Agricultural production results in large quantities of crop wastes. In some parts of the U.S., the wastes are burned in the field to clear remaining straw and stubble after harvest, and to prepare the field for the next cropping cycle. Other approaches to managing these wastes include plowing them back into the field, composting or landfilling them, or collecting them for use as a biomass fuel or as supplemental feed.

This chapter addresses field burning of agricultural crop wastes. When crop residues are burned, a number of greenhouse gases are released, including carbon dioxide, methane, carbon monoxide, nitrous oxide, and nitrogen oxides.

This chapter addresses only the CH_4 and N_2O emissions that result from combustion of crop residues. Emissions of carbon monoxide and nitrogen oxides are not addressed because these are gases whose greenhouse effect is indirect, and has not been quantified in a "global warming potential" value. Carbon dioxide emissions from crop residue burning are not considered because the carbon released as carbon dioxide during burning had been taken up from carbon dioxide in the atmosphere during the growing season.

This chapter addresses CH_4 and N_2O emissions from burning residues of three crops for which burning of crop wastes is significant in the US—rice, sugarcane, and wheat. Field burning may also result in enhanced emissions of N_2O and NO_x many days after burning (Anderson *et al.*, 1988; Levine *et al.*, 1988), but this process is highly uncertain and is not addressed in this chapter.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 11.2-1 summarizes the agricultural and forestry activities associated with emissions of CO_2, CH_4, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

Table 11.2-1. GHG Emissions from the Agricultural and Forest Sectors
A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✔	1	✔	13	✔	13
Animal Production: Enteric Fermentation			✔	6		
Animal Production: Manure Management						
Solid Storage			✔	7	✔	7
Drylot			✔	7	✔	7
Deep Pit Stacks			✔	7	✔	7
Litter			✔	7	✔	7
Liquids/Slurry			✔	7	✔	7
Anaerobic Lagoon			✔	7	✔	7
Pit Storage			✔	7	✔	7
Periodic land application of solids from above management practices					✔	Not included [a]
Pasture/Range (deposited on soil)			✔	7	✔	9
Paddock (deposited on soil)			✔	7	✔	9
Daily Spread (applied to soil)			✔	7	✔	9
Animal Production: Nitrogen Excretion (indirect emissions)					✔	9
Cropping Practices						
Rice Cultivation			✔	8		
Commercial Synthetic Fertilizer Application					✔	9
Commercial Organic Fertilizer Application					✔	9
Incorporation of Crop Residues into the Soil					✔	9
Production of Nitrogen-fixing Crops					✔	9
Liming of Soils	✔	9				
Cultivation of High Organic Content Soils (histosols)	✔	Not included [a]			✔	9
Cultivation of Mineral Soils	✔	Not included [a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✔	Not included [a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✔	10				
Abandonment of Managed Lands	✔	10				
Changes in Forests and Woody Biomass Stocks	✔	10				
Agricultural Residue Burning			✔	11	✔	11

[a] Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

3

OVERVIEW OF AVAILABLE METHODS

The methodology for estimating greenhouse gas emissions from field burning of agricultural wastes is based on (1) the amounts of carbon and nitrogen in the crop residue combusted, (2) the emission ratio of CH_4 to carbon released in combustion (as measured in the smoke of biomass fires), and (3) the emission ratio of N_2O to nitrogen released in combustion. To estimate emissions of CH_4 and N_2O from burning of agricultural wastes, the following steps are necessary: (1) obtain the required data on rice, sugarcane, and wheat production; (2) estimate the total amount of carbon and nitrogen released; and (3) estimate emissions of CH_4 and N_2O based on the amount of carbon and nitrogen released.

The methods described here are taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). These methods are used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 1998). However, the U.S. greenhouse gas inventory accounts for CH_4 and N_2O emissions not only from burning of rice,

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

sugarcane, and wheat residues, but also from burning of barley, corn, soybean, and peanut residues.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

The preferred method consists of seven steps, which are outlined below. Worksheets are provided at the end of this section to assist in the analysis.

Step (1) Obtain Required Data on Rice, Sugarcane, and Wheat Production

- *Required Data.* The information needed to estimate greenhouse gas emissions from burning of agricultural wastes is the annual production of rice, sugarcane, and wheat.

- *Data Source.* State agricultural agencies should be consulted first. Alternatively, annual crop production data may be found in the USDA report *Crop Production* (USDA 1998).

- *Units for Reporting Data.* Annual crop production should be reported in pounds. If production data are reported in hundred weight (CWT), multiply by 100 to convert to pounds. For grain data reported in bushels, the conversion factors are 60 lbs./bushel for wheat and 45 lbs./bushel for rice.

Example According to the USDA's report *Crop Production 1996*, total U.S. wheat production in 1996 was **2,281,763,000 bushels**.

2,281,763,000 bushels × 60 lbs./bushel = **137 billion pounds**

Step (2) Calculate the Amount of Dry Matter Burned (Table 11.4-1, Columns A-G)

- For each crop, calculate the amount of dry matter burned. Table 11.4-1 is provided to assist the user with this step. In column A, enter the amount of crop produced (in pounds, by crop type). Using the default data provided in Table 11.4-1—which are also used in the US EPA's national inventory of greenhouse gas emissions (US EPA 1998)—multiply columns A-F to obtain pounds of dry matter burned.

  Amount of Dry Matter Burned (lbs.) = Annual Crop Production (lbs.) × Residue/Crop Ratio × Proportion of Crop Produced in Fields where Residue is Burned (%) × Dry Matter Content of the Residue (%) × Burning Efficiency (%) × Combustion Efficiency (%).

Burning Efficiency is defined as the fraction of dry biomass exposed to burning that actually burns. Combustion Efficiency is defined as the fraction of carbon in the fire that is released to the atmosphere.[1]

Example	The quantity of wheat residue burned in 1996 is calculated as follows:
	137 billion lbs. × 1.3 lbs. residue/lb. crop product × 0.03 portion of crop produced in fields where residue is burned × 0.85 dry matter content × 0.93 burning efficiency × 0.88 combustion efficiency = **3.7 billion lbs. dry matter (dm)**

Step (3) Calculate Total Carbon Released (Table 11.4-2, Columns H-J)

- For each crop, take the amount of dry matter (dm) burned (estimated in step (2) -- column G) and enter it in column H of Table 11.4-2. Next, multiply the amount of dry matter burned by the fraction of carbon to obtain total amount of C released.

  Dry Matter Burned (lbs.) × Carbon Content of the Residue (lbs. C/lb. dm) = Total Carbon Released (lbs.)

Example	The total amount of carbon released from burning of U.S. wheat residue in 1996 is calculated as follows:
	3.7 billion lbs. dm × 0.4853 (lbs. C/lb. dm) = **1,800,000,000 lbs. C**

Step (4) Estimate Emissions of CH_4 (Table 11.4-3, Columns M, O, and P)

- For each crop, multiply the amount of C released in units of carbon by the emission ratio of CH_4 (column O) relative to total C.

  Amount Released (lbs. C) × (0.005) = CH_4 Emissions (lbs. CH_4-C)

[1] In the methodology recommended by the IPCC, the "burning efficiency" is assumed to be accounted for in the factor for "fraction of residues burned." However, the number used here to estimate the "fraction of residues burned" does not account for the fraction of exposed residue that does not burn. Therefore, a "burning efficiency factor" is added to the calculations.

Example CH_4-C emissions from burning of residue from U.S. wheat production in 1996 are calculated as follows:

CH_4-C Emissions: 1,800,000,000 lbs. C × 0.005 = **9,000,000 lbs. CH_4-C**

Step (5) Estimate Nitrogen Content of the Dry Matter (Table 11.4-2, Columns J, K, and L)

- For each crop, multiply the amount of carbon released by the ratio of nitrogen to dry matter in the crop residues. Ratios of nitrogen to dry matter for selected crop residues are presented in Table 11.4-2, column K.

  Dry Matter Burned (lbs.) × Nitrogen Content (lbs. N/lb. dm) = Total Nitrogen Released (lbs. N)

Example The total amount of nitrogen released from U.S. wheat residue in 1996 is calculated as follows:

Nitrogen Released: 3.7 billion lbs. dm × 0.003 (lbs. N/lb. dm) = **11,100,000 lbs. N**

Step (6) Estimate Emissions of N_2O (Table 11.4-3, Columns N, Q, and R)

- For each crop, multiply the amount of nitrogen released (Column N) by the N_2O-nitrogen emission ratio (column Q) to obtain emissions of N_2O-nitrogen.

  Amount of N Released (lbs.) × (0.007) = N_2O -nitrogen Emissions (lbs. N_2O -N)

Example N_2O-N emissions from burning of residue from U.S. wheat production in 1996 are calculated as follows:

N_2O-N Emissions: 11,100,000 lbs. N × 0.007 = **77,700 lbs. N_2O-N**

Step (7) Convert to Metric Tons of Carbon Equivalent (Table 11.4-3, Columns P and R)

- For each crop, perform the calculations shown in columns P and R of Table 11.4-3 to convert the emissions to units of metric tons of carbon equivalent. These calculations convert (1) emissions of CH_4-C and N_2O-N to full molecular weights, (2) pounds to metric tons, and (3) metric tons of gas to metric tons of carbon equivalent (by multiplying by the mass ratio of carbon to carbon dioxide, and by the global warming potential for each gas). The global warming potential (GWP) for methane is 21; the GWP for N_2O is 310.

- For each gas, sum across all crop types to produce total emissions from burning of crop residues.

Example Emissions of CH_4 and N_2O from burning of residue from U.S. wheat production in 1996 are converted to metric tons of carbon equivalent (MTCE) as follows:

CH_4 Emissions: 9,000,000 lbs. CH_4-C **x** (16/12) ÷ 2205 lbs./metric ton **x** (12/44) **x** 21 = **31,200 MTCE CH_4**

N_2O Emissions: 77,700 lbs. N_2O-N **x** (44/28) ÷ 2205 lbs./metric ton **x** (12/44) **x** 310 = **4,700 MTCE N_2O**

Tables 11.4-1, 11.4-2, 11.4-3: Emissions from Agricultural Residue Burning Worksheets

Table 11.4-1

	A	B	C	D	E	F	G ($A \times B \times C \times D \times E \times F$)
Crop Type	**Crop Production (lbs.)**	**Residue/Crop Ratio**	**Proportion of Residue Burned**	**Proportion of Dry Matter**	**Burning Efficiency**	**Combustion Efficiency**	**Dry Matter Combusted (lbs.)**
Rice		1.4	0.03	0.85	0.93	0.88	
Sugarcane		0.8	0.03	0.62	0.93	0.88	
Wheat		1.3	0.03	0.85	0.93	0.88	

Table 11.4-2

	H (Column G)	I	J ($H \times I$)	K	L ($H \times K$)
Crop Type	**Dry Matter Combusted (lbs. dm)**	**Carbon Content (lbs. C/lb. dm)**	**Total C Released (lbs. C)**	**Nitrogen Content (lbs. N/lb. dm)**	**Total Nitrogen Released (lbs. N)**
Rice		0.4144		.0067	
Sugarcane		0.4235		.0040	
Wheat		0.4853		.0028	

Note: Residual crop ratios, dry matter contents, carbon contents, and nitrogen contents were obtained from Strehler and Stützle (1987) and University of California (1997).

Table 11.4-3

	M (Column J)	N (Column L)	O	P $M \times O \times (16/12) \div 2205 \times (12/44) \times 21$	Q	R $N \times Q \times (44/28) \div 2205 \times (12/44) \times 310$
Crop Type	**Total Carbon Released (lbs. C)**	**Total Nitrogen Released (lbs. N)**	**CH_4-C Emissions Ratio**	**CH_4 Emitted (metric tons carbon equivalent)**	**N_2O-N Emissions Ratio**	**N_2O Emitted (metric tons carbon equivalent)**
Rice			0.005		0.007	
Sugarcane			0.005		0.007	
Wheat			0.005		0.007	
Total						

Source: Crutzen and Andreae, 1990.

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ALTERNATE METHODS FOR ESTIMATING EMISSIONS

No alternate methods have yet been approved by the Greenhouse Gas Committee of the Emission Inventory Improvement Program.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emission estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

The method presented in this chapter results in relatively crude estimates with substantial uncertainties. The use of region-specific emission ratios, which would account for the type of burning and other factors specific to the region, would allow for more precise calculations. The emission ratios presented here are based on measurements taken in a wide variety of fires. In many cases, these ratios are averages for all biomass burning. Further research could indicate whether emission ratios specific to a given region and the type of biomass burned may be developed. Also, emission ratios vary significantly between the flaming and smoldering phases of a fire. CO_2 and N_2O are mainly emitted during the flaming stage, while CH_4 is mainly emitted during the smoldering stage. The relative importance of these two stages will vary between fires in different ecosystems and under different climatic conditions, and so the emission ratios will vary.

Another issue that should be noted is that the basic calculations described here ignore the contemporary fluxes associated with past burning activities. These releases are known to exist, but are poorly understood at present. There are also other issues currently not treated in these calculations. For example, long-term changes in soil carbon are certainly possible as a result of agricultural practices. In fact, depending on the specific agricultural soil management practices used, including burning, there may be a variety of effects on soil carbon. For example, repeated burning of crop residues in fields may cause an increase in the amount of carbon stored in the soil over time. The longer-term release and uptake of these gases following burning is another important research issue, and may be included in future refinements of the calculations.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (e.g., the amount of dry matter burned), and the others are related to the emission factor (e.g., the amount of N_2O released per ton of dry matter burned). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to ten, where ten represents a high level of reliability. To derive the DARS score for a given estimation method, for each of the four attributes the activity level score is multiplied by the emission factor score, and the product is divided by ten. The resulting values are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the US government sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data.

TABLE 11.6-1

DARS SCORES: GREENHOUSE GAS EMISSIONS FROM BURNING OF AGRICULTURAL CROP WASTES

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	4	Because the emission factors for each crop are not based on measurement, the highest possible score is 5.	4	The amount of crop residues burned is estimated to be three percent for each crop in each state (based on state inventory data reports). The DARS formula does not apply to this scenario.	0.16
Source Specificity	5	The emission factors were developed for crop residues in general; expected variability is high.	5	The activity measured (crop production) is somewhat correlated to the emission process (crop burning).	0.25
Spatial Congruity	9	The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level crop burning and emissions. However, spatial variability is assumed to be low.	10	States use state-level activity data to estimate state-wide emissions.	0.90
Temporal Congruity	9	The emission factor is based on mass balance, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.	10	States use annual activity data to estimate annual emissions.	0.90
				Composite Score	**0.55**

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